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Comparing the economic value of virtual water with volumetric and stress-weighted approaches: A case for the tea supply chain

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Abstract

In this paper, we employ a new approach to assessing the impact and efficiency of virtual water use along the supply chain. This approach involves estimating the economic value of virtual water flows. A realistic tea supply chain case study is presented to test this new approach and compare it with alternative volumetric and stress-weighted methods. The case study is used to highlight the total value of the blue and grey water used to produce one tonne of tea as a finished good ($224). The case study also illustrates how variations in the relative unit value of water between geographies, in this case between multiple locations where crops are cultivated (India \$0.08 m^3, Indonesia \$0.09 m^3 and Kenya \$0.27 m^3), can be used to inform supply chain optimisation and allocative efficiency. Indeed, the case study suggests that taking into account the economic value of virtual water may provide differing prescriptions for the sustainable management of supply chains when compared to the traditional volumetric water footprint, and the stress-weighted water footprint used in LCA.

Keywords: Benefit transfer, economic value of water, stress-weighted water footprint, supply chain management, virtual water, Water Footprint.

1. Introduction

Less than 1% of the earth's water is easily accessible freshwater (USGS, 2016). This limited resource is subject to spatial and temporal disparities that are becoming more pronounced in light of multiple and interrelated socio-economic, demographic and environmental pressures (Vörösmarty *et al.*, 2000; Arnell, 2004; Kundzewicz *et al*., 2008). Indeed, by 2030 it is estimated that global water requirements will exceed sustainable supplies by 40% (2030 Water Resources Group, 2009), and the World Economic Forum consistently ranks "looming" freshwater crises as one of the most significant long-term global risks (World Economic Forum, 2018).

The complex and geographically diffuse nature of modern supply chains ensures that they are often the first to suffer in the face of water-related events. This vulnerability is particularly apparent with agri-food supply chains as they are both sustained by water resources but also significantly contribute to water scarcity (CERES, 2015). Globally, 70% of all water is used in agriculture (FAO, 2016) and approximately one-third of all cropland is located in areas of high or extremely high water stress (World Resources Institute, no date). As Morgan (2017) puts it, global water challenges are then, to a large degree, global sustainable food production challenges.

Against this backdrop, the concept of virtual water (Allan, 1996, 1998, 1999) – the volume of water used along a supply chain to produce products – has gained traction as a means of understanding how production and consumption in one location impacts watersheds in other locations. Virtual water studies have shown that it is the hidden component of water dependency associated with indirect water use in the supply chain that frequently represents by far the largest appropriation of freshwater (e.g. Aldaya and Hoekstra, 2010; Ercin *et al.*, 2011). Indirect water use is also an area that businesses neglect, thus exposing themselves to unknown risks and vulnerabilities.[1]

The main debate in the virtual water literature at present concerns the primary rubric for measuring sustainability. Should this be the efficient *allocation* of water *volumes* at the *global* scale as advocated by the Water Footprint Network (Hoekstra *et al.*, 2009; Hoekstra *et* al., 2011; Hoekstra, 2016)? Alternatively, should

[1] In the 2017 edition of the CDP Global Water Report, less than half (41%) of those companies surveyed engaged with their supply chain and required suppliers to report water management.

this be the *local impact* of water use at each supply chain location as indicated by *scarcity weighted water volumes* that can be used in Life Cycle Analysis (LCA) (Ridoutt, *et al.* 2009; Bayart *et al*., 2010; Ridoutt and Pfister, 2010; Kounina *et al*., 2013; Ridoutt and Pfister, 2013; Pfister and Ridoutt, 2014; Boulay *et al.*, 2015; Ridoutt *et al*., 2016; Pfister *et al.* 2017)? The application of environmental (economic) valuation, however, has not been introduced into this debate. Environmental (economic) valuation refers to the estimation of welfare values for goods and services provided by the natural environment. These goods and services are typically not responsive to markets, and therefore welfare or shadow values are used to signal relative resource scarcity and inform allocative efficiency (e.g. see Champ *et al*. 2003).[2] As Lowe *et al*. (2018a) argue, the correct estimation of welfare values has the potential to inform both the impact and allocation of virtual water dependencies.

Several authors have introduced economic-related concepts into the water footprint literature. For example, Chouchane *et al*. 2015 and Owusu-Sekyere *et al*. 2017 introduced the idea of economic water productivity. In addition, Input/Output frameworks have been used to derive the value-added of water in the supply chain (e.g. Acquaye *et al.* 2017). However, these approaches overstate shadow values as they are not focused on the contribution that water makes in isolation. Indeed, the most notable attempts to apply genuine welfare economic valuation concepts to water in the supply chain have occurred in the non-peer reviewed grey literature (PUMA, 2010; Ecolab and Trucost, 2015; Park *et* al. 2015; Ridley and Boland, 2015). These approaches set out in the grey literature have been used by companies such as PUMA, Kering, Bloomberg and Novo Nordisk.

In view of this, Lowe *et al*. (2018b) set out a new approach that involves estimating the economic value of the blue, green and grey water employed along agri-food product supply chains, using existing empirical water value estimates. In this paper, we provide an in-depth illustration of this new approach in the context of a simple four-stage tea supply chain case study (tea case study) that reveals the total value of the virtual water associated with the product. More importantly, however, the method also illustrates how variations in the value of water between multiple locations (in this instance locations of crop cultivation),

[2] Savenije (2002), Hanemann (2006) and Young and Loomis (2014) set out the market and institutional failures associated with water goods and services.

could be utilised to drive allocative efficiency along a supply chain and thus inform supply chain sourcing and optimisation.

The rest of the paper is organised as follows: Section 2 introduces the tea case study and the secondary data sources utilised to estimate the volumetric water footprint. Section 3 presents the unit economic value estimates that have been used at each stage of the supply chain, together with the economic value of the virtual water associated with tea. Section 4 discusses the benefit of an economic valuation approach to assessing the sustainability of virtual water use when compared to alternative methods (volumetric and scarcity-weighted footprints). Section 5 undertakes sensitivity analysis on the economic values used in the case study and sets out limitations associated with the approach adopted. Finally, Section 6 concludes.

2. The Volumetric Water Footprint of Tea – A Secondary Data Case Study

This paper begins by presenting the secondary data that we have drawn on to estimate of the volumes of water employed along the tea supply chain. This data provides a context in which to test the economic valuation approach that is the wholly novel aspect of this research and which we go on to describe here. Therefore, given that the water volume data is a means to an end, we do not provide a detailed description of this data here. For a fuller description of the methods used by the original authors, readers should consult the papers cited.

2.1. Case Study Background

The case study is based loosely on Jeffries *et al.* (2012) who use the Water Footprint method (Hoekstra *et al*., 2011) to estimate the volumes of blue and green water consumption, and grey water degradation that are associated with one box containing 50 grams of black tea.[3] However, when the emphasis is on economic values (as it will be in what follows), larger production quantities are more meaningful units of analysis. This is because the economic value of water only tends to register in volumes that exceed those associated with individual products. Therefore, the water footprint associated with one tonne of black tea –

[3] Blue water refers to surface and ground water. Green water is rainfall stored in the soil as moisture. Grey water is the volume of water needed to assimilate pollution. Water consumption refers to water that is no longer available at a place and point in time because, for example, it has evaporated or been incorporated into a product (Hoekstra *et al*. 2011).

20,000 50g boxes – will be the focus here, with linear aggregation assumed. While it is acknowledged that there may be some economies of scale associated with larger production quantities, there will also be water use associated with additional packaging and palletisation. It is therefore assumed that the overall effect is a zero-sum outcome.

The key stages in the production of tea are set out in the supply chain map shown in Figure 1 together with their geographical location.

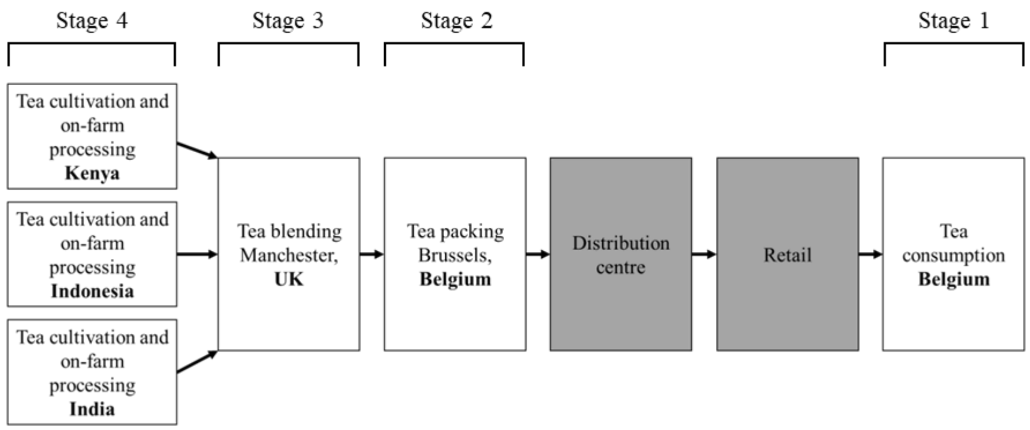

Figure 1. Tea supply chain map. Stages in grey are excluded from the analysis of the water footprint. Adapted from Jeffries *et al.* (2012).

Crop cultivation (Stage 4) occurs in the Rift Valley (Kericho) and Central Highlands (Nyeri) of Kenya, in the Jawa Barat province of Indonesia (Agrabinta), and in the state of Himachal Pradesh in northern India (Kangra district). With the exception of the regional location in India, each of these locations has been taken from Jeffries *et al*. (2012). The location in India was selected due to the availability of corresponding water valuation data that will be introduced in Section 3, as well as the fact that the Kangra district is a major tea-producing region. As shown in Table 1 – which sets out the top 15 tea producing countries in 2016 together with the associated country average water footprint – each of the three countries where tea is sourced from in the supply chain resides in the top ten global tea producing nations. Following Stage 4, the tea is first sent to the UK (Manchester) for blending (Stage 3), before it is packed (Stage 2) in Belgium (Brussels). Final consumption of the tea by the end consumer (Stage 1) is assumed to occur in Brussels.

Table 1
The top 15 tea producing countries in 2016

Countries	Production quantity 2016 (tonnes) [a]	% contribution to global production [a]	Yield (tonne/ha) [a]	Country average water footprint (m^3/tonne) [b]		
				Green	Blue	Grey
China	2,414,802	40.56%	1.08	9,277	798	1,496
India	1,252,174	21.03%	2.14	4,778	1,332	360
Kenya	473,000	7.94%	2.16	4,061	4	89
Sri Lanka	349,308	5.87%	1.51	10,306	-	1,421
Turkey	243,000	4.08%	3.18	2,296	735	160
Vietnam	240,000	4.03%	2.02	12,490	191	485
Indonesia	144,015	2.42%	1.23	11,172	-	257
Myanmar	102,404	1.72%	1.19	37,609	951	214
Argentina	89,609	1.50%	2.38	7,641	1,222	246
Japan	80,200	1.35%	1.82	4,996	55	2,081
Iran	75,000	1.26%	3.68	1,827	8,791	444
Bangladesh	64,500	1.08%	1.07	10,997	-	113
Uganda	63,322	1.06%	2.15	5,842	-	2
Burundi	52,701	0.89%	4.38	10,816	-	2
Thailand	52,619	0.88%	6.41	36,622	5,836	1,774
World	5,954,091	100.00%	1.45	7,232	898	726

Note: These figures are for broad country comparison and have not been used in the specific analysis in this chapter.
[a] FAOSTAT (2017). [b] Mekonnen and Hoekstra (2011).

Jeffries *et al.* (2012) excluded grey water in their estimation of the tea water footprint. Their rationale for this was that, in their study, which was a comparative analysis between the Water Footprint approach and LCA, the latter appears to have been unable to address water quality issues in a way that fell within the scope of the work. As a result, grey water was excluded altogether. Given this, as will be detailed in what follows, where possible the data in Jeffries *et al.* (2012) has been supplemented with data from the Water Stat database (Mekonnen and Hoekstra, 2011) to re-introduce volumes of grey water which remain of interest in this context.

2.2. Volumetric Data – Blue and Green Water Consumption and Grey Water Degradation

Using the standard nomenclature utilised in the Water Footprint Assessment Manual (Hoekstra *et al.*, 2011), four components constitute the water footprint of tea. Each of these components may be associated with blue, green and grey water burdens.[4] The four components are:

1. The supply chain water footprint directly associated with inputs – this refers to the water footprint of the ingredients (e.g. tea) and other inputs (e.g. packaging) that go into making the product.

[4] In practice, green water is only linked to agriculture and forestry.

2. The operational footprint directly associated inputs – this refers to the volume of water either consumed or polluted during the production and processing of tea at stages 2 (Manchester) and 3 (Brussels).
3. The supply chain overhead water footprint – this refers to the water footprint of the materials used in the factories at stages 2 and 3 that cannot be associated with one particular product. For example, this might include the water footprint of the paper and energy used in the factories, as well as the concrete used to build the factories.
4. The operational overhead water footprint – this refers to the water used in supporting activities in the factories at stages 2 and 3 that again cannot be fully linked to the production of a specific product. For example, this would include the water used to flush toilets and for cleaning and hygiene.

In addition to the above, given that there is a consumer use phase associated with drinking tea, the end-use water footprint is also estimated.

2.2.1. Supply chain water footprint directly associated with inputs

The primary ingredient in the production of a 50-gram box of tea is black tea, the raw material and process water footprints associated with which are detailed in Table 2 for each of the four locations at Stage 4. As referred to above, the data from Jeffries *et al.* (2012) on the raw material water footprint of tea has been substituted for data from Mekonnen and Hoekstra (2011). This substitution has been done to include the volumes of grey water that correspond to the tea crop. The grey water footprint calculated by Mekonnen and Hoekstra (2011) refers to the volumes of water necessary to dilute the nitrogen fertiliser applied during tea cultivation.

Table 2
The water footprint of black tea

Location	Water footprint m^3/tonne of raw material [a]				Process water requirement m^3/tonne [b]			
	Green	Blue	Grey	**Total**	Green	Blue	Grey	**Total**
Kenya (Kericho)	4,117	5	94	**4,216**	0	0.12	0	**0.12**
Kenya (Nyeri)	3,721	4	72	**3,797**	0	0.12	0	**0.12**
Indonesia (Agrabinta)	11,354	0	277	**11,631**	0	0.12	0	**0.12**
India (Kangra district)	4,116	741	285	**5,141**	0	0.12	0	**0.12**

[a] Mekonnen and Hoekstra (2011). [b] Estimate derived from process water requirement and product fraction listed in Jeffries *et al.* (2012). As mentioned above, grey water was excluded by Jeffries *et al.* (2012), and as a result, is not included in the process water requirement here.

While Jeffries *et al.* (2012) do not explicitly record the percentage that black tea, from each of the four locations at Stage 4 constitutes of the end product (i.e. the blend of tea in the end product), it is possible to extrapolate this information as shown in Table 3.[5]

Table 3
Composition of tea in the end-product

Kenya (Kericho)	Kenya (Nyeri)	Indonesia (Agrabinta)	India (Kangra district)
67%	7%	17%	10%

Note: Extrapolated from Jeffries *et al.* (2012).

In addition to tea, Jeffries et al. (2012) also estimate the water footprint associated with packaging inputs (tea bag materials and other packaging). For one box of tea, the associated water footprint was estimated at 29.6 litres, the vast majority of which is green water. Given that Jeffries et al. (2012) were not able to define a specific location for the generic inputs that comprise packaging, it is assumed here that the associated water burden falls at the packing factory in Belgium.

2.2.2. Operational water footprint directly associated with inputs

Data for the operational water footprint (0.005 litres/50g tea) has been sourced from Jeffries *et al.* (2012). However, Jeffries *et al.* (2012) did not report how this water footprint component breaks down between the two factory stages, i.e. stages 2 and 3. Therefore, it has been assumed here that this component is split evenly between the two factory locations (i.e. Manchester and Brussels).

2.2.3. Supply chain and operational overhead water footprints

Data for the supply chain (1.6 litres/50g tea) and operational (0.003 litres/50g tea) overhead water footprints have again been sourced from Jeffries *et al.* (2012). However, Jeffries *et al.* (2012) were not specific about how these footprint components break down between stages 2 and 3. Therefore, it has again been assumed that these components split evenly between the two factory locations (i.e. Manchester and Brussels).

The supply chain overhead water footprint, like the water footprint associated with packaging inputs, is non-geographically specific given that it is comprised of generic items bought and sold on world markets.[6]

[5] The extrapolated percentages accord with the limited information that Jeffries *et al.* (2012) do refer to regarding the tea blend as they mention that tea from India represents approximately 10%.
[6] Jeffries *et al.* (2012) accounted for the building materials (concrete and steel), paper and energy used in the factories at stages 2 and 3 of the supply chain.

Consequently, in this context, it is assumed that the water use associated with the supply chain overhead footprint occurs in the factory locations at stages 2 and 3.

2.2.4. The end-use water footprint

Jeffries *et al.* (2012) estimate that the water footprint linked to the consumption of tea is approximately 5 litres per 50g box, all of which is blue water. This volume is comprised of 2.2 litres of water associated with tea consumption, and 2.8 litres associated with the electricity used to boil the water.[7]

2.2.5. Out of scope

Since grey water was excluded in the Jeffries *et al.* (2012) study, visibility over degradative water volumes is consequently limited here. However, by sourcing data from Mekonnen and Hoekstra (2011) on the water use during crop cultivation at Stage 4, this has been rectified for the stage in the supply chain that accounts for the greatest use of water resources (approximately 90% of total green and blue water is associated with Stage 4). In addition, while the operational and operational overhead water footprint data associated with stages 2 and 3 excludes grey water volumes, given the advanced nature of the countries concerned (i.e. the UK and Belgium), it seems reasonable to assume that any wastewater would be returned via the sewerage network to a treatment plant. If so, grey water associated with these two footprint components would be zero. Furthermore, the tea packing and blending processes at stages 2 and 3, with which the operational and operational overhead footprints are associated, both consume negligible volumes of water, and the packing and blending of tea are not processes that give rise to water-borne pollutants.

However, both the water footprint associated with packaging inputs and the supply chain overhead footprint may have an associated grey water footprint. Given their small size in volume terms though, lack of visibility on the grey water associated with these components is a recognised limitation in this context.

2.3. The Water Footprint of One Tonne of Tea

Table 4 sets out the total water footprint for one tonne of tea as a finished good (20,000 boxes). As mentioned, the water footprint of one tonne of tea is based on linear aggregation of the water footprint of one

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[7] The water use allocated to tea consumption assumes that 35% of ingested water evaporates through breathing and perspiration. The remaining water is assumed to be returned to the same basin that it was extracted from thus constituting a non-consumptive use (Jeffries *et al.*, 2012). Based on a typical 250g box of tea containing 80 bags that has been consulted here for reference, a 50g box would contain 16 bags and therefore account for approximately 137.5 ml per bag (i.e. 2,200 ml/16 bags).

box of tea. Table 4 also shows how the components of the water footprint are allocated between the four supply chain stages shown in Figure 1.

Table 4

The water footprint of one tonne of tea as a finished good (20,000 boxes) (m^3)

Supply chain stage	Location	Description	Water footprint component	Green	Blue	Grey	**Total**	% of total
4 [a]	Kenya (Kericho)	Tea cultivation and processing	Supply chain	2,743.5	3.28	62.54	**2,809.32**	45.0
4 [a]	Kenya (Nyeri)	Tea cultivation and processing	Supply chain	247.95	0.24	4.79	**252.98**	4.1
4 [a]	Indonesia (Agrabinta)	Tea cultivation and processing	Supply chain	1,891.64	0.02	46.16	**1,937.82**	31.1
4 [a]	India (Kangra district)	Tea cultivation and processing	Supply chain	413.03	74.37	28.60	**516**	8.3
3 [b]	UK (Manchester)	Blending	Supply chain overhead	9	7	0	**16**	0.26
3 [b]	UK (Manchester)	Blending	Operational	0	0.05	0	**0.05**	>0.1
3 [b]	UK (Manchester)	Blending	Operational overhead	0	0.03	0	**0.03**	>0.1
2 [c]	Belgium (Brussels)	Packing (Packaging)	Supply chain	580	12	0	**592**	9.5
2 [b]	Belgium (Brussels)	Packing	Supply chain overhead	9	7	0	**16**	0.26
2 [b]	Belgium (Brussels)	Packing	Operational	0	0.05	0	**0.05**	>0.1
2 [b]	Belgium (Brussels)	Packing	Operational overhead	0	0.03	0	**0.03**	>0.1
1 [d]	Belgium (Brussels)	Tea consumption	End use	0	100	0	**100**	1.6
Total				**5,894.12**	**204.07**	**142.09**	**6,240.28**	**100**

[a] Mekonnen and Hoekstra (2011). [b] Jeffries *et al.* (2012). As referred to above, this assumes that the supply chain overhead, operational and operational overhead water footprints are split evenly between the production facilities in Manchester (Stage 3) and Brussels (Stage 2). [c] Jeffries *et al.* (2012). As referred to above, this assumes that the water burden associated with packaging inputs is located in Brussels. [d] Jeffries *et al.* (2012). As referred to above, this assumes that tea consumption occurs in Brussels.

As shown in Table 4, and as recognised by Jeffries *et al*. (2012), nearly 90% of the volumetric water footprint of tea is attributable to the tea crop at Stage 4. Indeed, in absolute terms based on *total* volume data, tea cultivation in Kericho (45%) and Agrabinta (31.1%) appear to be the areas of greatest water impact. Alternatively, if the consumption of limited global blue water resources is the most important criterion, then the water used in Kangra district (95.5% of blue water consumption at Stage 4 and 36.4% of blue water consumption across stages 1 to 4), and during the consumer use phase at Stage 1 (49% of blue consumption across stages 1 to 4), appear to be the areas of greatest concern. However, this analysis is based solely on the volumes of water in the supply chain and does not take account of the economic value of these volumes and how this varies by use and by geography. Therefore, we now introduce a new perspective that looks to estimate the economic value of virtual water along the supply chain, before comparing the utility of this approach with alternative methods for assessing virtual water in Section 4.

3. The Economic Water Footprint of Tea

In this section, we begin by outlining the unit values (i.e. denominated in volumetric terms) that have been assigned to each stage of the supply chain. We then go on to estimate the economic value of the virtual water employed along the tea supply chain.

3.1. Unit Values Assigned at Each Stage of the Supply Chain

The values utilised here have all been drawn from Lowe *et al.* (2018b) who undertook a detailed review of the unit values of water that have been published and referenced in specialist environmental valuation databases. These databases included The Environmental Valuation Reference Inventory (EVRI), ValueBase SWE, Envalue, The New Zealand Non-Market Valuation Database, and The Economics of Ecosystems and Biodiversity (TEEB) Valuation Database. The reference sections of those papers found were also searched for additional relevant material. The focus of the review encompassed off-stream applications (agriculture/irrigation, industry and municipal) and several in-stream functions that are also impacted when water is withdrawn and then consumed or degraded (recreation, waste assimilation and wildlife habitat). Table 5 summarises the 706 unit value estimates that were collated from 120 sources. All estimates were standardised in 2014 USD using World bank PPP exchange rates for GDP and the Implicit Price Deflator for GDP from the Bureau for Economic Analysis (BEA, 2016; World Bank, 2016). The estimates include capitalised asset and non-capitalised asset (or per period) values, all of which have adopted a private accounting stance.

Table 5
Unit values recorded in Lowe et al. (2018b) by category

	Agriculture	Industry	Municipal	Waste assimilation	Wildlife habitat	Recreation
No. of estimates [a]	365	131	106	13	42	49
No. of countries [a]	22	7	15	1	1	1
Median value USA 2014 $/Acre Foot [b]	$65.02	$21.31 [d]	$91.96	$2.05	$55.61	$13.32
Median value ROW 2014 $/Acre Foot [c]	$148.44	$618.09 [d]	$482.83	-	-	-

Note: [a] Value estimates include per period and capitalised asset values. [b] Median per period value of those recorded in the USA. [c] Median per period value of those recorded in the Rest of the World (ROW). [d] Excludes values that have been estimated by the residual value, added value and cost of intake approaches as these are no longer seen as appropriate for valuing industrial water usage.

The water values are applied here using benefit (value) transfer which involves deploying values that have been estimated in one context (the study site), to a new context (the policy site; in this case the locations of each supply chain stage) utilising a range of approaches (Bergstrom and Taylor, 2006; Richardson *et al.*, 2015; Rosenberger and Loomis, 2003; Wilson and Hoehn, 2006). Only the values associated with off-stream extractive uses (agriculture, industry and municipal) were found to be available in great enough numbers for any meaningful benefit transfer exercise. Therefore, only the direct use value of water in the supply chain is considered here, using the specific benefit transfer techniques for each category of water use as set out in what follows. Indirect use values and passive-use values as they are referred to within a Total Economic Value framework, are not included (Pearce and Turner, 1990).

3.1.1. Blue water

The direct use values attributed to blue water at each of the four stages of the tea supply chain will be considered below, starting with Stage 1 and the blue water that is consumed during tea consumption.

3.1.1.1. Consumer use phase (Stage 1)

The water used in the consumer use phase is split between tea consumption (44%) and the water associated with the electricity that is needed to boil the kettle (56%). A standard two-part formula for a simple household demand function has been utilised here to value the tap water used in the home to consume tea (i.e. the 44%). The first part of the formula derives the value of treated water delivered to the home; the second part estimates the net consumer surplus that is equivalent to the value of raw water in the stream. The two parts of the formula are repeated directly below (Young and Loomis, 2014). In conjunction with the inputs in Table 6, an at-site value of \$4.38 (part 1) and an at-source value of \$0.36 (part 2) were estimated, both per cubic metre.

Part 1 $V = [(P\ x\ Q_1^{\frac{1}{E}})\ /\ (1 - \frac{1}{E})]\ *\ [(Q_1^{1-\frac{1}{E}}) - (Q_2^{1-\frac{1}{e}})]$ [1]

Part 2 $CS = V - [(P_1)(Q_1 - Q_2)]$ Where: E = Elasticity P = Price Q = Quantity [2]

Table 6
Residential (tap) water value – Demand function inputs

Input	Value	Source
Q1	96.3 litres per person per day (10% reduction on Q2).	
Q2	107 litres per person per day; 39 m^3 per annum.	Environment Agency (2008)
Price (2014 USD)	4.02 [a]	Global Water Intelligence (2016)
Price elasticity estimate	-0.62	Vanhille (2012)
At-site value (2014 USD per m^3)	4.38	
At-source value (2014 USD per m^3)	0.36	

Note: [a] Assumes two people per household and monthly billing (marginal rate falls into the > 6 cubic metre block tariff charged in Brussels).

3.1.1.2. Industrial water use (stages 2 and 3)

The water used by industry in Manchester and Brussels in the direct operations of each factory (i.e. not the operational overhead or the supply chain overhead water footprints), has been valued with reference to two sources highlighted in Lowe *et al.* (2018b). There it was argued that Wang and Lall (2002) and Bruneau (2007) provide the most robust and appropriate estimates of the value of water consumed in a wide variety of industries, from what is a limited pool of research on the value of water as an intermediate input to industry. Table 7 shows the values that Wang and Lall (2002) and Bruneau (2007) have derived specifically for water that is consumed by the food industry. In what follows, the average of the two values shown in Table 7 ($2.39) will be utilised.

No value will be assigned to the operational overhead and supply chain overhead water footprints here or the water footprint associated with packaging inputs. In all three cases, this is because these categories encompass too much variation for an appropriate value to be transferred. For example, the supply chain overhead water footprint is made up of a variety of goods and services (including as mentioned earlier, building materials, paper and energy) used in the Manchester and Brussels factories that cannot be directly associated with one final product. However, neither the supply chain overhead water footprint nor the water footprint associated with packaging inputs are geographically specific. Therefore, they will never be a relevant change variable when comparing water values in different regions. In addition, the operational overhead water footprint represents less than 1% of the total water footprint of tea.

Table 7
Food industry values used in the tea case study

Supply chain location at stages 2 and 3 (Policy site)	Source	Method	Value type	Water volume measure	Original value m^3 (currency)	2014 \$/m^3
UK and Belgium	Wang & Lall (2002)	Production function	MV	Consumption	2.57 (Yuan)	1.87
UK and Belgium	Bruneau (2007)	Alternative cost	AV	Consumption	2.5 (CAD)	2.92
						2.39 (Average)

Note: MV = Marginal Value. AV = Average Value.

3.1.1.3. Agricultural water use (Stage 4)

Table 8 sets out the values that have been drawn from the detailed literature search presented in Lowe *et al.* (2018b) that returned 365 estimates of the value of irrigation water in different locations. In the case of Kenya, the values are for irrigation water in the Kerio Basin, which is proximate to both Nyeri and Kericho. For Indonesia, the values employed are for irrigation in East Java, which is contiguous to West Java where Agrabinta is located. Similarly, in India, the irrigation water values utilised are for the region of Haryana in the north of the country, which is contiguous to Himachal Pradesh where the Kangra district is located. All of the values in Table 8 represent water applied or diverted as none were available for water that is consumed. As such, they represent a lower bound estimate of the value of water consumed at each location.

Unlike stages 1 to 3 in the supply chain that each have a single location, there are three locations for Stage 4. Consequently, the *relative* value between Stage 4 locations becomes important if the analysis is to compare the impacts of water use at each location. As a result, the values presented in Table 8 have been selected because, as far as possible, they are comparing a common scenario. For instance, all of the values in Table 8 have been estimated using the farm crop budget approach (FCB) (or a derivative of this) which yields an average value per unit of water. However, while every care has been taken to ensure a consistent comparison, Table 8 shows that there are exceptions vis-à-vis volumetric measure, water source and whether the value is an at-site or at-source measure. More broadly, each of the estimates is also sensitive to the exact crop and, for example, the precise components used in the FCB approach, many of which are not fully discernible in the respective sources.

As such, the values in Table 8 should be considered indicative only; although they represent the best data available, they are relatively few in number and would need to be investigated using fully consistent primary valuation techniques in each location if a policy-relevant action was contingent on them. This requirement is particularly true if the results were to be generalized beyond the local scale, as is the intention here. Finally, while tea is not a low valued crop, estimates for higher valued crops in each location were not available. Therefore, the values for low valued field crops in Table 8 again represent a lower bound value in this context

3.1.2. Grey water

It is assumed here that the unit value of grey water degradation is equal to the unit value of blue water consumption. This assumption has been made because: 1) grey water refers to the volume of blue water that is necessary to assimilate pollution, and 2) as with water consumption, we assume that when water is degraded it is no longer available for off-stream functions at a particular point in space and time. We recognise that this assumption may not hold for the grey water produced in agriculture as run-off can still have a positive fertilisation effect. However, agricultural run-off can be polluted with, for example, pesticides and metals. In addition, there is the potential for run-off to lead to the mistimed or excessive application of fertiliser. Nonetheless, treating grey water as, in effect an opportunity cost, is a means of generating an upper bound estimate of the value of grey water.

3.1.3. Green water

Green water in this context is not rainwater as such but that portion of rainwater that is evapotranspired by the tea crop during its growth phases, or in other words, it is the volume of rainwater that is usefully absorbed by the crop. As such, following the method set out in Lowe *et al.* (2018b), it was anticipated that values for artificial irrigation water consumed by the crop would be used as a proxy for the value of green water. Alternatively, if these were not available, then the at-source value of artificially applied irrigation water could be utilised as a lower bound value instead. Making use of either of these measures implicitly assumes that water is equally productive at each stage of the crop growth cycle, an assumption that may not hold for all crops and all climates. However, neither of these approaches were able to produce realistic estimates of the value of green water consumed in tea cultivation. As a result, green water will not be assigned an economic value in what follows, and this will be addressed directly in Section 5.3 when the limitations of the research are discussed.

Table 8

Agricultural values used in the tea case study

Supply chain location at Stage 4 (Policy site)	Source	Method	Value type	At-site/ at-source	Long run/short run	Water volume measure	Crop value	Original value m^3 (currency)	2014 \$/m^3	Study location (Study site)
Kenya (Kericho and Nyeri)	Kiprop *et al.* (2015)	Farm crop budget	AV	At-site	Short	Application	Low (millet)	4.3 (Kenyan Shilling)	0.11	Kenya (Kerio Basin)
Kenya (Kericho and Nyeri)	Kiprop *et al.* (2015)	Farm crop budget	AV	At-site	Short	Application	Low (sorghum)	11.28 (Kenyan Shilling)	0.30	Kenya (Kerio Basin)
Kenya (Kericho and Nyeri)	Kiprop *et al.* (2015)	Farm crop budget	AV	At-site	Short	Application	Low (maize)	14.87 (Kenyan Shilling)	0.40	Kenya (Kerio Basin)
AVERAGE									**0.27**	
Indonesia (Agrabinta)	Rodgers & Hellegers (2005)	Farm crop budget	AV	At-site	Unclear	Application	Low (rice)	0.02 – 0.05 (USD)	0.03 – 0.07	Indonesia (Brantas Basin - East Java)
Indonesia (Agrabinta)	Rodgers & Hellegers (2005)	Farm crop budget	AV	At-site	Unclear	Application	Low (maize)	0.08 – 0.11 (USD)	0.11 – 0.15	Indonesia (Brantas Basin - East Java)
AVERAGE									**0.09**	
India (Kangra district)	Rogers *et al.* (1998)	Yield comparison [a]	AV	At-site	Short	Diversion	Low (rice and wheat)	0.019 (USD)	0.03	Northern India (Haryana)
India (Kangra district)	Hellegers & Perry (2004)	Farm crop budget	AV	At-source	Short	Application	Rice	0.025 (USD)	0.03	Northern India (Haryana)
India (Kangra district)	Hellegers & Perry (2004)	Farm crop budget	AV	At-source	Short	Application	Rice [b]	0.02 (USD)	0.02	Northern India (Haryana)
India (Kangra district)	Hellegers & Perry (2004)	Farm crop budget	AV	At-source	Short	Application	Wheat	0.132 (USD)	0.16	Northern India (Haryana)
India (Kangra district)	Hellegers & Perry (2004)	Farm crop budget	AV	At-source	Short	Application	Wheat [b]	0.127 (USD)	0.16	Northern India (Haryana)
AVERAGE									**0.08**	

Note: AV = Average Value. Values converted from local currency to 2014 USD using World Bank PPP exchange rates for GDP and the BEA Implicit Price Deflator for GDP (BEA, 2016; World Bank, 2016). [a] Also known as the change in net rents approach.[b] Groundwater.

3.2. The Total Value of Blue Water in the Supply Chain

Figure 2 sets out the unit values assigned to blue water consumption at each stage along the tea supply chain, and the value of the specific volume of blue water used at each stage. For each of the four locations at Stage 4, an average of those values recorded in each location has been utilised (Table 8). However, Section 5 will undertake several sensitivity analyses to take account of the range of values on display in Table 8 and what is an unknown level of transfer error at each Stage 4 location.

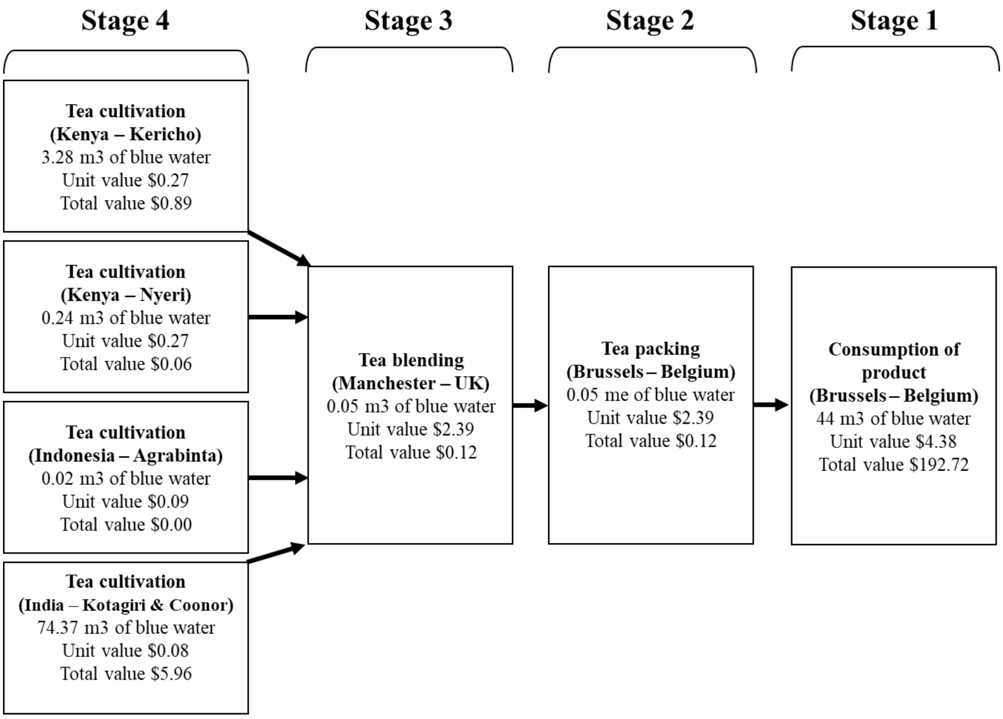

Figure 2. Blue water values assigned to each stage of the tea supply chain. Note: 1) values for stages 2 and 3 refer to the operational water footprint only, and 2) value for Stage 1 refers to the 2.2 litres of water associated with tea consumption in the home.

As shown in Table 9, 96.4% of the total value of blue water consumed in the supply chain occurs during the consumer use phase (Stage 1). This is despite the fact that Stage 1 only accounts for approximately 36.1% of the volume of blue water that has been subject to valuation (i.e. not including those blue water volumes set out in Section 3.1 that were excluded). This disparity is primarily driven by the comparatively high at-site unit value assigned to treated municipal water at Stage 1, and it ensures that while 61% of the total volume of blue water use occurs in India, this only accounts for 3% of the total value.

Looking at Stage 4 in isolation, Kericho accounts for 4.2% of the volume of irrigation water consumed. However, this volume represents 12.8% of total value given the relatively high unit value assigned to irrigation water in Kenya by comparison to Indonesia and India. Similarly, irrigation water used in India accounts for 95.5% by volume but only 86.2% by value given that the unit value in India is the lowest of those on display. These results are beginning to suggest the differences highlighted by taking a value-based perspective.

The total direct use value of blue water consumed in the production of one tonne of tea is $199.87, or, using the nominal exchange rate in mid 2019 (1 USD = 0.79 GBP), approximately £157.

Table 9

Blue water value and volume distribution in the tea supply chain

Stage (location)	Volume of blue water (m^3)	Unit value (2014 $/$m^3$)	Value of blue water consumed (2014 $)	% of total blue water volume [a]	% of total blue water value	% of Stage 1 volume	% of Stage 1 value
4 (Kenya – Kericho)	3.28	0.27	0.89	2.7	0.4	4.2	12.8
4 (Kenya – Nyeri)	0.24	0.27	0.06	0.2	<0.1	0.3	0.9
4 (Indonesia)	0.02	0.09	0.00	<0.1	<0.1	<0.1	<0.1
4 (India)	74.37	0.08	5.96	61.0	3.0	95.5	86.2
3 (UK – Manchester)	0.05	2.39	0.12	<0.1	0.1		
2 (Belgium – Brussels)	0.05	2.39	0.12	<0.1	0.1		
1 (Belgium – Brussels) [b]	44	4.38	192.72	36.1	96.4		
Total	**122.01**		**199.87**	**100**	**100**	**100**	**100**

Note: [a] The percentage of blue water volume refers to the volumes of blue water that are subject to valuation and does not include those aspects of the supply chain described in Section 3.1 that are beyond the scope of the valuation exercise. [b] The water consumed at Stage 1 refers to the volume of water associated with tea consumption only; it does not include the water associated with the electricity used to boil the kettle (Section 2.2.4).

3.3. The Total Value of Grey Water in the Supply Chain

Figure 3 presents the value of grey water along the supply chain. This is based on the approach set out in Section 3.1.2, which involves utilising the unit value estimates derived for blue water consumption. As presented in Section 2.2, there is no grey water associated with stages 1 to 3 of the supply chain.

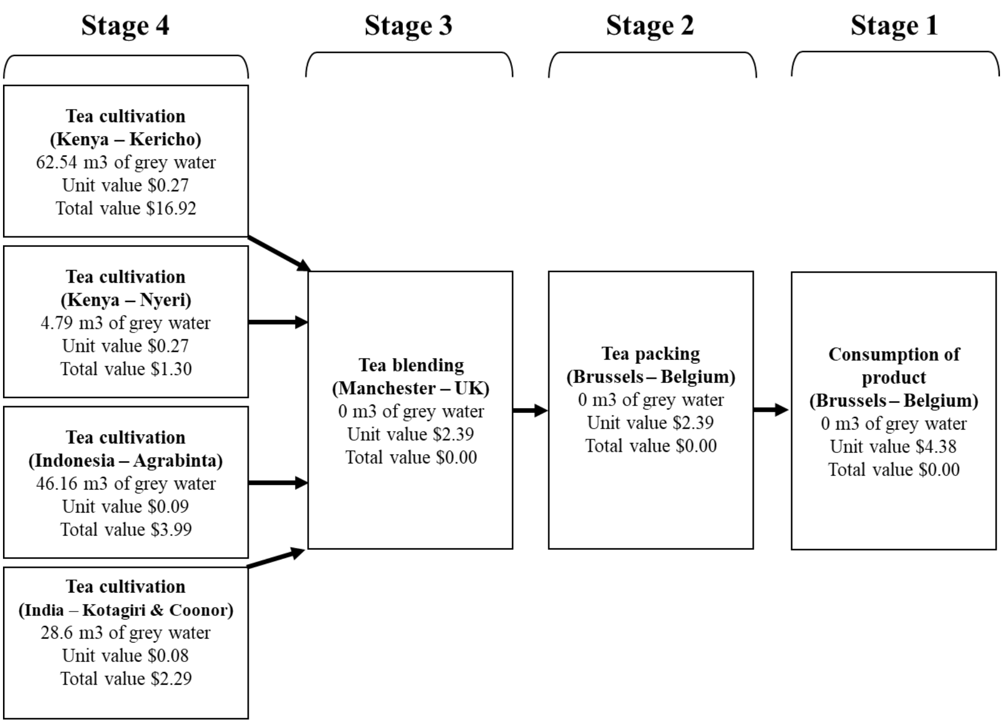

Figure 3. Grey water values assigned to each stage of the tea supply chain.

Table 10 shows the total value of the grey water in the tea supply chain and how this total breaks down by location. Owing to the disparities in unit values between locations that were noted above, grey water in Kericho represents 69.1% of total value but only 44% of total volume. Similarly, grey water in India represents 20.1% by volume but only 9.4% of total value. The total value of the grey water associated with one tonne of tea is $24, or, using the nominal exchange rate mentioned previously, approximately £19.

Table 10
Grey water value and volume distribution in the supply chain

Stage (location)	Volume of grey water (m^3)	Unit value (2014 $/$m^3$)	Value of grey water degraded (2014 $)	% of total grey water volume	% of total grey water value
4 (Kenya – Kericho)	62.54	0.27	16.92	44.0	69.1
4 (Kenya – Nyeri)	4.79	0.27	1.30	3.4	5.3
4 (Indonesia)	46.16	0.09	3.99	32.5	16.3
4 (India)	28.60	0.08	2.29	20.1	9.4
Total	**142.09**		**24.49**	**100**	**100**

3.4. The Total Value of Blue and Grey Water in the Supply Chain

Table 11 sets out the total value associated with the water footprint of one tonne of tea as a finished good (20,000 50g boxes). As referred to, the scope of the valuation exercise excludes the operational overhead and supply chain overhead water footprints, together with the water associated with packaging and the electricity used during tea consumption, all of which encompass too much variation to assign a meaningful economic value. In addition, as will be addressed in what follows, the large volumes of green water used in tea cultivation are similarly excluded. The total value of the blue and grey water consumed in the production of one tonne of tea is $224 or £176. Detailed data on the cost of other inputs into production is not readily available to contextualise this figure. However, in Sri Lanka (which is not part of the analysis here but is nevertheless a major tea producer) the cost of fertilizer and pest and disease control applications used in tea cultivation has been estimated at 24,790 Sri Lankan Rupees per tonne of tea (2017/8 figures) (AESD, 2019). Using the nominal exchange rate in mid-2019 (1 USD = 176.49 Rupees), this equates to approximately $140 which is broadly comparable to the value of water employed along the supply chain.

Table 11

The total value of the blue and grey water used to produce one tonne of tea (finished goods)

Water footprint component	Value/cost USD 2014	Value/cost GBP
Blue	200	157
Grey	24	19
Total value	**224**	**176**

Table 12 shows how the total value of blue and grey water breaks down by supply chain stage. It is the high at-site unit value assigned to tap water at Stage 1, combined with the substantial volumes of blue water (44 m^3 per tonne) that are consumed in the drinking of tea, which ensures that this stage accounts for 86% of total value. Indeed, the value of water at Stage 1 obscures the differences in value between the multiple locations at Stage 4, imbalances in which highlight the real merit of an economic approach such as this and the geographical trade-offs that it enables.

Table 12

Total blue and grey water value by supply chain stage

Stage (location)	% of total blue and grey water value
4 (Kenya – Kericho) Blue water	<1
4 (Kenya – Kericho) Grey water	8
4 (Kenya – Nyeri) Blue water	<1
4 (Kenya – Nyeri) Grey water	1
4 (Indonesia) Blue water	<1
4 (Indonesia) Grey water	2
4 (India) Blue water	3
4 (India) Grey water	1
3 (UK) Blue water	<1
2 (Belgium) Blue water	<1
1 (Belgium)Blue water	86
Total	**100**

4. Comparing Approaches – Water Footprint, Stress-Weighting, and Economic Valuation

Geographical variations in economic value and the trade-offs that this facilitates become more pronounced if we ignore the blend of tea in the end product (Table 3) and concentrate on the economic value of a common quantity of tea cultivated in each Stage 4 location (Section 4.1). Doing so will then allow us to more easily compare the prescriptions suggested by an economic valuation approach with those suggested by the traditional water footprint and stress-weighted water footprint (Section 4.2).

4.1. The Economic Value Associated with a Common Quantity of Tea

Table 13 presents the value of the blue and grey water associated with a common quantity (one tonne) of tea cultivated in each Stage 4 location. This analysis is not based on the tea blend in Table 3 and does not include the water associated with stages 1 to 3.[8]

Table 13
Total value of the blue and grey water used to produce one tonne of tea in each location

Stage 4 location	Blue water (m^3) [a]	Grey water (m^3) [a]	Unit value (2014 $/$m^3$)	Total value of blue water (2014 $)	Total value of grey water (2014 $)	Total value of blue and grey water (2014 $)
India	741	285	0.08	59.36	22.83	**82.19**
Kenya - Kericho	5	94	0.27	1.35	25.43	**26.78**
Indonesia	0	277	0.09	0	23.93	**23.93**
Kenya - Nyeri	4	72	0.27	1.08	19.48	**20.56**

[a] Mekonnen and Hoekstra (2011).

Economic value with its foundations in the concept of Willingness to Pay (WTP) reflects the intensity of individuals' preferences for water. Accordingly, economic theory suggests that efficient inter-sectoral water allocation would see the same unit of water flowing to the highest valued use. However, when the focus is on different drops of water as it is here, the prescription from welfare economics would seem to differ. Now, the optimum outcome would see tea being sourced from the Stage 4 location that exhibits the lowest, not highest, water value. Alternatively, given that economic values are no longer in evidence when water is consumed or degraded, they effectively represent costs, and therefore sourcing from the location with the lowest value would represent the optimal solution. In light of this, it is clear from Table 13 that while Kenya exhibits the highest unit value of blue and grey water ($0.27 per cubic metre), Nyeri accounts for the lowest volume of

[8] Table 13 utilises the water volumes presented in Table 2, and the economic values assigned to blue and grey water volumes at Stage 4 that were introduced in Section 3.1.

blue and grey water consumed (76 m^3) and thus the lowest overall value ($20.56) in volume adjusted terms. Nyeri, therefore, appears to be the optimal sourcing location, followed by Indonesia, Kericho, and then India as the least optimal sourcing location

4.2. Comparing Economic Valuation with the Water Footprint and Stress-Weighted Approaches

The Water Footprint advocated by the Water Footprint Network is traditionally associated with the identification of virtual water volumes. However, this approach can also take account of the vulnerability of local water systems using the water stress index, as well as the volumes of water consumed, to inform sourcing scenarios (Hoekstra *et al.*, 2011). The water stress index measures the ratio of total annual water withdrawals in an area to total annual water availability, and it can be used to assess the impact of blue water usage in the supply chain and thus identify blue water hotspots. Following the approach set out in Jeffries *et al.* (2012), a hotspot occurs where "the blue water footprint of products is large and where water scarcity is high," the latter being defined as where it exceeds a value of 0.6 (P.159).

Table 14 sets out the water stress values for each of the sourcing locations at Stage 4 using data from the World Resources Institute (2013). Table 14 suggests that Kangra district in India is a potential hotspot given the fact it supplies 10% of the tea at Stage 4 and exhibits a water stress value of 0.75.

Table 14
Baseline Water Stress values for Stage 4 tea sourcing regions

Country	State/region	Baseline water stress [a]	% of tea sourced from
India	Kangra district	0.75	10
Kenya – Nyeri	Nyeri	0.12	7
Indonesia	Agrabinta	0.09	17
Kenya – Kericho	Kericho	0.04	67

Note: [a] World Resources Institute (2013).

From a stress-weighted water footprint perspective, Table 15 illustrates the combined blue and grey stress-weighted water footprint based on the water volume data in Table 13 and the Baseline Water Stress data shown in Table 14. India is again identified as a hotspot. Indeed, as summarised in Table 16, which sets out the sourcing preferences highlighted by the different approaches, India is consistently identified as the least optimal sourcing location across all of the approaches included here. However, by including economic value, it becomes possible to differentiate clearly between the remaining three locations, all of which exhibit similar levels of blue water scarcity (Table 14). Most tellingly in this respect, Indonesia is clearly a more favourable sourcing location from an economic perspective when compared Kericho (total value of blue and grey water

$23.93 versus $26.78), and this is despite the fact that the former pollutes and consumes nearly three times the volume of water when compared to the latter (277 m^3 versus 99 m^3). This insight again highlights the importance of taking the value of water and not just the volume of water into account, and it provides a different policy recommendation when compared to the other approaches outlined.

Table 15
Stress-weighted water footprint associated with one tonne of tea in each location

Stage 4 location	Blue water (m^3)	Grey water (m^3)	Total blue and grey water (m^3)	Baseline water stress	Stress-weighted water footprint (m^3 ecosystem-eq).
India	741	285	1,026	0.75	**769.5**
Indonesia	0	277	277	0.09	**24.93**
Kenya - Nyeri	4	72	76	0.12	**9.12**
Kenya - Kericho	5	94	99	0.04	**3.96**

In addition, unlike the stress-weighted water footprint, an economic approach allows the cost savings that would be realised if tea was sourced from one location versus another to be identified. For example, this saving would amount to $61.63 if a tonne of tea was sourced from Nyeri as opposed to India ($82.19 - $20.56), *ceteris paribus*. Indeed, by placing water dependencies in economic terms, the resulting measure has the potential not just to address local impact, but also to drive the broader global water resource allocation decisions that have been the focus of the Water Footprint community if incentives such as these materialise. Similarly, differences in relative unit values between locations may also incentivise productive efficiencies. For example, the relatively low unit value in India could incentivise improvements in irrigation practice, the absece of which may explain the comparatively low unit value of water suggested here. An economic water footprint approach is also potentially more easily understood by the business community when compared to complex approaches based on LCA and stress weighting. If so, this would enable businesses to demonstrate responsible stewardship of the natural environment in a language with which they are more familiar. This common language would also enable easier comparisons with other location or sourcing decisions made by supply chain managers that will invariably be measured financially, and it it may enable a closer link to other emerging value-based environmental issues such as carbon credit costs. In addition, an economic water footprint approach may also be more intuitively understandable to audiences outside of the business world, a factor that was a key part of the widespread appeal and adoption of the initial volumetric Water Footprint concept.

Table 16
Comparison between sustainability indicators

	Water Footprint approach using volume data only	Water Footprint approach including baseline water stress	Stress-weighted water footprint	Economic valuation approach
Preference 1	Kenya (Nyeri)	No clear prescription	Kenya (Kericho)	Kenya (Nyeri)
Preference 2	Kenya (Kericho)	No clear prescription	Kenya (Nyeri)	Indonesia
Preference 3	Indonesia	No clear prescription	Indonesia	Kenya (Kericho)
Preference 4	India	India	India	India

This analysis is based on limited available evidence regarding the unit values that prevail in each geography. As a result, the standard convergent validity techniques that would usually be applied in benefit transfer exercises to estimate transfer error in each location are not feasible. Therefore, given the sensitivity of the conclusions to the precise unit values applied in each location, and the importance of the *relative* differences in unit values between locations, we now move on to sensitivity analysis to ascertain the degree of certainty around the conclusions drawn thus far. However, to understand the differences in unit values on display in Table 13 fully, entirely consistent primary valuation data would need to be gathered, as it would if any policy-relevant decision was contingent on the analysis presented.

5. Sensitivity Analysis and Limitations

Two sensitivities will be deployed here. The first looks at the transfer errors that would bring about convergence between the unit values in the three locations. The second will look at the volume adjusted values set out in Table 13 and estimate the increases in value that would be necessary in the lowest valued location (Nyeri, Kenya) for it to be comparable with the other volume adjusted values. As part of this second sensitivity, the likelihood that in-stream values in Nyeri, which are impacted when water is consumed and degraded, could account for this increase in overall value, will also be addressed.

5.1. Sensitivity One

Table 17 sets out the level of transfer error that would bring about convergence between the unit values at each location. For example, an 8% transfer error would mean that the Indian value was comparable with the Indonesian value, and a 238% transfer error would ensure that the Indian value was comparable with the Kenyan value. This is based on the standard formula for estimating transfer error as set out below, the only difference being that the observed and transferred values refer to separate locations (Czajkowski and Scasny, 2010):

$$E_{TR} = \frac{WTP_{transferred} - WTP_{observed}}{WTP_{observed}} \quad [3]$$

Table 17
Transfer errors that would be necessary to bring about convergence between unit values in each location

Country comparison	2014 $/m^3	Difference in unit values $/m^3	Transfer error
Kenya and India	0.27	0.19	238%
Indonesia and Kenya	0.09	0.18	213%
India and Indonesia	0.08	0.01	8%

Czajkowski and Scasny (2010) suggest that the majority of transfer errors are in the 0-200% range. However, in this context, the potential for transfer error is magnified when comparing values across two countries, given that this level of error could potentially apply to one or both locations. Indeed, because of this, it is not possible to say with a high degree of certainty that the least optimal sourcing location from a unit value perspective would be Kenya. This is despite the fact that there would need to be transfer errors of 238% and 213% for the Kenyan unit value to converge with the unit values in India and Indonesia, respectively. Put another way, a 200% transfer error applied to the unit value in Kenya *and* India or Indonesia could see these values overlap and thus alter the conclusions drawn. Nonetheless, what we can say is that absent a sizeable error, the indications are that Kenya is not the optimal sourcing location from a unit value perspective. Indeed, referring back to the unit values in Table 8, while there was some overlap between the lower range Kenyan value and the upper range Indonesian value, on a like for like basis growing maize, the value in Kenya was noticeably greater than in Indonesia ($0.40 compared to $0.11 – 0.15).

5.2. Sensitivity Two

Sensitivity two looks at how much the 76 m^3 of blue and grey water used in Nyeri (the location with the lowest volume adjusted value in Table 13) would have to increase by to be comparable with the other three locations analysed here. Table 18 (derived from Table 13) presents the difference in volume-adjusted value between Nyeri and each of the other locations (Column two). This difference is divided by 76 m^3 (Column three).

Despite the fact that Indonesia utilises 201 m^3 more blue and grey water than Nyeri in the cultivation of a tonne of tea (Table 13), given the disparity in unit values, it would only require a small (16%) increase in the unit value in Nyeri for the volume adjusted value to be comparable with Indonesia. Again, this highlights the importance of taking into account values as well as volumes. Conversely, however, it would require a

300% increase, or \$0.81 per cubic metre, for the volume-adjusted value in Nyeri to be comparable with India. Therefore, it seems reasonable to conclude here that India does not represent the optimum sourcing location in volume adjusted terms. Beyond this, Nyeri appears to be the optimum sourcing location form a volume-adjusted perspective, but this is relatively sensitive to increases in unit values (a 16% increase would bring it in line with Indonesia while a 30% increase would bring it in line with Kericho).

Table 18

Sensitivity two – unit value increases necessary to bring Nyeri in line with other sourcing locations

Location	Difference in total value of blue and grey when compared to Nyeri (2014 \$)	Increase in unit value of 76 m^3 of blue and grey (2014 \$)	% increase in \$0.27 unit value
Indonesia	3.37	0.044	16%
Kenya (Kericho)	6.22	0.082	30%
India	61.63	0.810	300%

In addition, the requisite unit value increases (Column three) can be compared with the instream value scale presented in Lowe *et al*. (2018b). This scale is based on the minimum, median and maximum *combined* waste assimilation, wildlife habitat and recreation values that were collated by Lowe *et al.* (2018b) from published sources. All of these in-stream values originated from the USA (and in particular the more arid parts of the southwest) which was the only country that has recorded these values to date. Indeed, this reflects the fact that the USA is at the forefront of environmental valuation and the unit valuation of water. The in-stream scale assumes that:

1) The benefits that stem from the ability of water to assimilate waste and provide wildlife habitat and recreational opportunities are present at the same time.
2) That the point of diversion is such that the values are all additional, both with each other and with the extractive use (in this case in agriculture). [9]
3) That there is no distance decay effect for recreational values.[10]

For example, the maximum in-stream value on the scale is based on the highest recorded unit values for waste assimilation, wildlife habitat and recreation. The point of the scale is to indicate whether the

[9] According to Brown (2004), off-stream economic values maybe additional to in-steam values provided that the latter are non-consumptive and dependent on the point of diversion, i.e. the point where water is diverted for off-stream use.

[10] The distance decay effect refers to means that people are more likely to be WTP for recreation the closer they are to the site in question (Hanley *et al.* 2003; Pate and Loomis, 1997).

presence of instream values in Nyeri, which would be impacted when water is extracted from the stream for consumption in agriculture, could potentially alter the conclusions reached.

The instream value scale can be adjusted for relative incomes in Kenya using the formula set out by Czajkowski and Scasny (2010) which assumes an income elasticity of one:

$$WTP_{ps} = WTP_{ss}\left(\frac{\overline{I_{ps}}}{\overline{I_{ss}}}\right)\varepsilon \quad [4]$$

where WTP_{ss} is willingness to pay at the study site, WTP_{ps} is the willingness to pay estimate transferred to the policy site, and I_{ss} and I_{ps} are mean income levels at the study and policy sites. ϵ represents the income elasticity of willingness to pay between the mean income levels at the study and policy sites (Czajkowski and Scasny, 2010). The income data in Table 19 has been used to make this adjustment, and the resulting in-stream value scale for Kenya is set out in Table 20.

Table 19
Relative income levels in Kenya

Country	GNI Per Capita [a]	% of USA GNI Per Capita
USA	52,308.38	100
Kenya	2,157.94	4

[a] UNDP (2014).

Table 20
In-stream value scale Kenya ($/m^3)

Low		Median		High
0.00002	→	0.002	→	0.025

As shown, it is quite clear that the necessary increases in unit values in Nyeri that would be needed for the volume adjusted value to comparable with Indonesia, Kericho and India are far beyond the highest in-stream values recorded to date (i.e. \$0.044 m^3, \$0.082 m^3 and \$0.81 m^3 are both greater than \$0.025 m^3).[11] Therefore, it seems reasonable to conclude that the presence of in-stream values in Nyeri, which would be impacted by water consumption and degradation, is unlikely to produce volume-adjusted values that exceed Indonesia, Kericho and India. However, this conclusion does not take into account in-stream values in Indonesia, Kericho and India, the presence of which would further widen the gulf in volume-adjusted value between the respective locations and Nyeri.

[11] Technically, in-stream values would be additional to agricultural values which are net of extraction costs (i.e. the agricultural value is an at-source value). However, given that at-source agricultural values were not available here in all locations, the in-stream value scale is applied to at-site agricultural values on the assumption of minimal/similar extraction costs across Stage 4 sourcing locations.

5.3. Limitations and Future Research Direction

Several limitations are attached to the analysis described here. First, as conceived by the Water Footprint (and thus by the authors who provided secondary data on the volumes of water in the tea supply chain), grey water is a theoretical as opposed to real volume of water. To subject grey water to economic valuation, we have assumed that there is not more pollution than assimilative capacity in the receiving water bodies at each supply chain location. Liu *et al.* (2012) suggest that, broadly, excessive nitrogen and phosphorous discharges are more prevalent in the southern hemisphere, and that high general water pollution levels are to be found in tropical-subtropical areas. Therefore, this assumption may not hold for all three countries at Stage 4. However, in the absence of more specific data, and given the low level of spatiotemporal detail that the method here is adhering to, this is a recognised limitation in this context and one which would need to be addressed using primary valuation techniques should decision relevant values be required.

Second, the economic valuation approach did not include the substantial volumes of green water consumed at each Stage 4 location. Green water was excluded because ultimately the value of water in crop cultivation is subject to a derived demand, i.e. a farmers WTP is dependent upon the income that is received for the crop. Therefore, any attempt to value the volumes of green water with reference to some measure of the value of artificial irrigation, produced value estimates that were far too large and therefore unrealistic. Furthermore, unlike grey water which could be viewed as an opportunity cost (i.e. the value that degraded water could have been put to if it had not been polluted), green water does not stem from a blue water source. Therefore, green water could not have been used for artificial irrigation if it had not been consumed, and thus, it cannot be treated as an opportunity cost.[12] As a result, the economic valuation of green water is an outstanding research question of note here given the strategic significance of green water resources (Aldaya *et al.* 2010), a fact that is well illustrated by the sizable volumes consumed in the tea supply chain.

Finally, given the importance of relative differences between unit values at Stage 4, and the constrained evidence base of prevailing values in each location, they would need to be confirmed using fully consistent primary valuation techniques at each Stage 4 location if decision relevant values were required.

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[12] Green water can be harvested. However, as Hoekstra *at al*. (2011) argue, rainwater harvesting mostly refers to “the collection of rain that otherwise would become run-off” (p.26). Given that harvesting will detract from run-off, Hoekstra *et al*. (2011) recommend considering harvested rainfall as blue water.

Indeed, the valuation of irrigation water across multiple regions using either primary valuation techniques or a more generalizable secondary data approach, also remain research questions of note for further investigation. So too does the value of water in industry and the in-stream value of water (Table 5). If this additional research were pursued, it would allow a values-based approach to be a more credible accompaniment to existing volumetric and stress-weighted water footprint approaches. By comparison, these existing approaches are not as constrained by a lack of appropriate data.

6. Conclusion

In conclusion, the water footprint of 20,000 50g boxes of tea representing one tonne of finished goods was estimated (6,240 m^3) using secondary data sources. It was shown that 90% of this water footprint was associated with the tea crop at Stage 4. Indeed, in absolute volume terms alone, it was suggested that the cultivation of tea in Kericho (Kenya) and Agrabinta (Indonesia) appear to be the areas of greatest concern. However, Kangra district (India) and the water used during the consumer use phase at Stage 1 account for the largest share of blue water consumption in the supply chain. This analysis was not based on a like for like comparison, but rather, the blend of tea that is found in the end product.

The total value of the blue and grey water used to produce one tonne of finished goods (i.e. 20,000 boxes) was estimated at $224. The vast majority of this value (86%) was associated with the water that is used during tea consumption, given the higher unit values linked to treated municipal tap water. Again, however, this analysis was based on the blend of tea in the end product and therefore was not able to fully illuminate the trade-offs between the multiple Stage 4 locations that become apparent when an economic approach is adopted.

For that reason, a like for like comparison of the value of blue and grey water used to cultivate a tonne of tea in each location was undertaken. This comparison showed that while Nyeri (Kenya) exhibits the highest blue water *unit value* (absent a transfer error in excess of 200%; Table 17), because it uses the least blue and grey water, in *volume adjusted* terms it accounts for the least *total* value of water. However, a 16% or 30% increase in the unit value in Nyeri would ensure that the volume-adjusted value was in line with Indonesia and Kericho (Kenya) respectively (Table 18). Given that it would require a 300% increase in the unit value in

Nyeri to bring volume-adjusted value in line with India, the principal overall conclusion seems to be that India likely represents least optimal sourcing location even though it has the lowest unit value.

This conclusion accords with the volumetric analysis of the blue and grey water consumed and degraded in the production of a common quantity of tea at each Stage 4 location. In addition, it accords with the analysis of blue water hotspots from the perspective of the Water Footprint and stress-weighted water footprint. Nonetheless, beneath this overall conclusion it was only by taking the economic value of water into account that it becomes apparent, for example, that Indonesia would clearly be a preferred sourcing location when compared to Kericho, despite the fact that the former pollutes and consumes nearly three times the volume of water when compared to the latter. Furthermore, it is only by estimating economic values that potential shadow value savings, *ceteris paribus*, can be revealed. Indeed, one of the principal benefits of the economic valuation approach is that businesses may well find it more intuitive than some of the alternative methods assessed.

Clearly, the availability of additional empirical value estimates that can be used in approaches such as that described here would lead to greater confidence in the results arrived at which should be considered indicative only. However, as this case has shown, shifting to estimating the economic value of virtual water along the supply chain has the potential to provide additional insight into sustainable and responsible sourcing and supply chain management decisions.

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